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Indian Standard

VELOCITY AREA METHODS FOR MEASUREMENT OF FLOW OF WATER IN OPEN CHANNELS

(First Revision)

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Indian Standard

VELOCITY AREA METHODS FOR MEASUREMENT OF FLOW OF WATER IN OPEN CHANNELS

(First Revision)

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Indian Standard

VELOCITY AREA METHODS FOR MEASUREMENT OF FLOW OF WATER IN OPEN CHANNELS

(First Revision)

0. FOREWORD

0.1 This Indian Standard (First Revision) was adopted by the Indian Standards Institution on 22 September 1981, after the draft finalized by the Fluid Flow Measurement Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 Since the first publication of this standard in 1959 an ISO standard, ISO 748, on the subject has been printed and also revised. Therefore, it has become necessary to examine the provisions contained in the ISO standard with a view to reconciling the differences. Further, certain comments were received on this standard regarding the provision of number of verticals to be used for measurement in regular canals, location of current meters with respect to the boat, effect of sediment, etc, and these aspects were referred to the Fundamental and Basic Research Committee of the Central Board of Irrigation and Power and this standard takes cognizance of the results of these studies. Reference to the Slope Area Method has been deleted since a separate standard IS : 2912-1964* has been published.

0.3 Open channels, where this method is employed for discharge measurements, may be classified as:

a) Rivers and natural drainage channels in which there can be no control on either the velocity or the sectional area through which the water is flowing.

b) Channels where the section generally remains unchanged and only velocity is changing. This is often the case with lined channels.

c) Channels where both the section and velocity are under control and are generally constant as in artificial channels.

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*Recommendation for liquid flow measurement in open channels by slope-area method (approximate method).

0.4 In all these three cases, measurement of flow involves (a) measurement of the sectional area through which water is discharging, and (b) measurement of velocity. Where the cross-sectional area is constantly changing, as in the case of rivers, to determine discharge, it is necessary to measure both the cross-section and the velocity every time the measurement is taken. Where the section of flow is constant, as in the case of rigid channels, it is necessary to measure the section once only and thereafter measurement of flow involves only the determination of velocity. In canals and other channels, where both the section of flow and the velocity are constant, the measurement of flow is further simplified and a suitable device can be introduced into the system to record the flow directly.

0.5 In the formulation of this standard due weightage has been given to International coordination among the standards and practices prevailing in different countries in addition to relating it to the practices in the field in this country. This has been met by deriving assistance from ISO 748-1979 'Liquid flow measurement in open channels — Velocity area methods' issued by the International Organization for Standardization.

0.6 This standard is one of the series of standards on measurement of flow in open channels.

0.7 In reporting the results of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS : 2-1960*.

1. SCOPE

1.1 This standard deals with the measurement of flow of water in open channels by measuring the velocity of water and the area of the cross-section of flow. This does not apply with the same degree of accuracy to waterways subject to tidal influence, pulsating flow and rapidly varying stage discharges. This standard deals only with single measurements of the discharge; the continuous recording of discharges over a period of time has been covered in IS : 2914-1964†.

2. TERMINOLOGY

2.1 For the purpose of this standard, the definitions given in IS : 1191-1971‡ shall apply.

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*Rules for rounding off numerical values (*revised*).

†Recommendations for estimation of discharges by establishing stage-discharge relation in open channels.

‡Glossary of terms and symbols used in connection with the measurement of liquid flow with a free surface (*first revision*).

3. UNITS OF MEASUREMENT

3.1 The units of measurement used in this Indian Standard are SI.

4. SELECTION AND DEMARCATION OF SITE

4.1 Initial Survey of Site — The several possible sites where discharge observations are proposed shall first be selected after a careful study of the available maps. These sites shall then be inspected and initial surveys conducted to determine which of these sites is most suitable satisfying the requirements specified in this standard.

4.1.1 These surveys shall include approximate measurements of widths, depths, velocities and direction of currents to serve as a guide that both the longitudinal and transverse bed profiles and the velocity distribution are acceptable for the purpose of discharge measurement.

4.2 Selection of Site — The accuracy of the determination of the discharge by the velocity area method is increased, if:

a) the channel is straight and its cross-section is well defined;

b) the conditions of flow do not change within the period of measurement;

c) the velocities at all points are parallel to one another and at right angles to the measuring cross-sections;

d) the velocity contours (iso-vels) are regular in the vertical and horizontal planes on which they are measured.

4.2.1 The site selected should comply, as far as possible, with the following essential requirements:

a) The reach of the open channel at the gauging site shall be straight and of uniform cross-section and slope, as far as possible, in order to avoid irregularities in velocity distribution. The length of the reach need not be more than 1 600 m and should not be less than 400 m. When the length of the straight channel is restricted, it is recommended for current meter measurements that the straight length upstream of the measuring cross-section should be twice that downstreams.

NOTE — In case of artificial channels, the minimum length of straight reach should preferably be such as to give a drop in water level of 0·06 m, or the minimum length should be equal to four times the width of the channel, whichever is larger.

b) The depth of water in the selected reach shall be sufficient to provide for the effective immersion of either the current-meters or floats, whichever are to be used.

c) When near a confluence, the site, if located on a tributary shall be sufficiently upstream preferably beyond the backwater effect; and if located on the main-stream, upstream or downstream of the confluence, it shall be beyond the disturbances due to the tributary.

d) The site should be easily accessible at all times of the year.

4.2.2 In addition to the requirements specified in **4.2.1**, the following points shall be taken into consideration as desirable requirements in the selection of the gauging site:

a) The flow should be confined in a single channel and there should be no overflow as far as possible. Where this is not possible, the site in which minimum number of channels exist and the flood plain has minimum width should be preferred.

Where these requirements cannot be met (for instance, when in alluvial rivers the riverbed is changing during the period of measurement, or when, under flood conditions, the river is not confined to a single channel in embankments), a gauging-site shall be chosen such that the bed change and/or overflow is a minimum. Flood-plains if they cannot be avoided, shall be of minimum width, as smooth as possible, with a distinct channel, and clear of bushes and trees. The flow in the over bank or flood plains section(s) shall be measured separately and added, treating the whole as a composite section.

b) The site shall be remote from any bend or natural or artificial obstruction if disturbance of the flow is likely to be caused thereby.

c) The orientation of the reach should be such that the direction of flow is as closely as possible normal to that of the prevailing wind.

d) Sites at which there is a tendency for the formation of vortex or development of return flow shall be avoided.

e) The site should, as far as possible, be free from trees and obstructions which may interfere with flow and clear vision during observation.

f) The site shall be free from aquatic growth which is likely to interfere with the measurement of depth and the current meter reading.

g) The site shall be away from the back water zone caused by any structure on the river.

h) The site should be selected sufficiently away from the disturbance caused by rapids and falls, etc.

4.3 Demarcation of Site

4.3.1 The site, after being selected, shall be demarcated in the manner specified in **4.3.3**.

4.3.2 The direction of water flow shall be determined by any suitable method and noted.

4.3.3 The measuring section shall be marked by means of concrete or masonry pillars erected on the two banks.

4.3.4 The stage shall be read from a gauge at intervals throughout the period of measurement and the gauge datum shall be related by precise levelling to a GTS Bench mark. Stages shall be measured to the accuracy as specified in IS : 2914-1964*.

4.3.5 An auxiliary gauge on the opposite bank shall be installed where there is likelihood of a difference in the level of water surface between the two banks. This is particularly important in the case of very wide rivers. The mean of the measurements taken from the two gauges should be used as the mean level of the water surface and as a base for the cross-sectional profile of the stream.

4.4 When the site is intended for establishment of stage discharge relation, relevant provisions of IS : 2914-1964* shall apply.

5. MEASUREMENT OF CROSS-SECTIONAL AREA AND VELOCITY

5.0 The cross-sectional area of flow at the gauging site shall be determined by measuring, at the cross-section, the depth relative to the water surface at a sufficient number of points to establish the shape of the bed.

The location of these points shall be determined by measuring their horizontal distance at a fixed reference point in the cross-section. In practice, these measurements determine the cross-sectional area of the individual segments between successive verticals where velocities are measured.

Alternatively, an echo sounder which provides a continuous bed profile quickly may be preferred.

5.1 Measurement of Width — The measurements of the width of the channel and the widths of the individual segments may be obtained by measuring the distances from or to a fixed reference point, which shall be in the same plane as the cross-section at the gauging site.

5.1.1 Where the width of the channel permits, or when the surface is covered by ice, these distances shall be measured by direct means, for example, a steel tape or suitable marked wire, care being taken to apply the necessary corrections given in Appendix A. The intervals between the verticals, that is the widths of the segments, shall be similarly measured.

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*Recommendations for estimation of discharges by establishing stage-discharge relation in open channels.

5.1.2 Where the channel is too wide for the above methods of measurements, the distances shall be determined by optical or electrical distance meters, or by one of the surveying methods given in Appendix B.

5.2 Measurement of Depth

5.2.1 *Number of Verticals* — Measurement of depth shall be made at intervals close enough to define the cross-sectional profile accurately. It would be safe to use 25 verticals for the observations of depth. The use of at least 20 verticals would restrict the error, while the use of 15 vertical means risking the introduction of errors of importance. This condition applies to big as well as small rivers.

NOTE — Velocity observations, particularly, with current meters should be made simultaneously with the depth observations, though the former may be made at a lesser number of verticals in special circumstances (*see* **5.3.1.1**).

An example of the values of uncertainties in the case of a wide river with irregular bed profile is given in Table 1.

TABLE 1 RELATIVE ERROR FOR CHOICE OF A DISCRETE NUMBER OF DEPTH VERTICALS IN A WIDE RIVER WITH IRREGULAR BED PROFILE

NUMBER OF VERTICALS m	UNCERTAINTIES (PERCENTAGE) (95% CONFIDENCE LEVEL)
Less than 10	More than 9
15	6
20	5
25	4
30	3
50	1·2

NOTE — The calculated discharge with a restricted number of verticals shows systematically to low results.

However, for artificial channels with regular cross-section smaller number of depth and velocity verticals may be adopted for relative uncertainty of ± 4 percent (95% confidence level) as indicated in Table 2.

TABLE 2 RECOMMENDED MINIMUM NUMBER OF VERTICALS FOR ARTIFICIAL CHANNELS

CHANNEL CAPACITY	APPROXIMATE SURFACE WIDTH	NO. OF VERTICALS FOR DEPTH AND VELOCITY
Above 85 m^3/s	Above 35 m	11
Between 15 and 85 m^3/s	Between 15 and 35 m	9
Less than 15 m^3/s	Up to 15 m	5

5.2.2 *Location of Verticals* — It is recommended to locate a number of verticals in characteristic parts of the cross-section (after previous sounding). The remaining verticals should be equally spaced within these parts. However, in the overland flow sections, the observations may be at a lesser number of equally-spaced verticals.

5.2.3 *Measuring Procedure* — The depth should be measured employing either sounding rods or sounding lines, or other suitable devices. Sounding rods shall be used for measuring depths up to 6 m and sounding line (log line) shall be used for depths greater than 6 m. Where the channel is of sufficient depth and velocity is high an echo-sounder* may be used.

NOTE — When measuring the depth under an ice cover on the water, it is necessary to determine the depth of the flowing water under the ice. If there is a layer to frazil ice, its thickness shall be excluded.

When a sounding rod or sounding line is used, at least two readings should be taken at each point and the mean value adopted for calculations, unless the difference between the two values is more than 5% of the larger value, in which case two further readings should be taken. If these are within 5 percent, they should be accepted for the measurement and the two earlier readings discarded. If they are again different by more than 5 percent, no further readings should be taken, but the average of all four readings should be adopted for the measurement, noting that the accuracy of this measurement is reduced.

When an echo-sounder is used, the average of several readings should preferably always be taken at each point, but regular calibrations of the instrument are required under the same conditions of salinity and temperature of the water.

Where it is impracticable to take more than one reading of the depth, the error in measurement may be increased (*see* 7).

NOTE 1 — Where measurements of the depths are made separately from the velocity measurements and the water level is not steady, it should be observed at the time of each measurement of depth. If this is not possible, the water level should be observed at intervals of 15 minutes and the value of the level at the time of each determination of depth should be obtained by interpolation.

NOTE 2 —If the bed is composed of unstable material (shifting sand, silt) repeated measurements by a rod or log line at one point are not recommended with a view to avoiding disturbance of the bed.

NOTE 3 — When, during the measurement of discharge, the bed profile changes appreciably, depth measurements should be carried out by taking at each point one reading at the beginning and one at the end of each measurement of velocity verticals, and the mean value of these two measurements should be taken as the effective depth.

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*For details *see* ISO 4366-1979 Echo sounders for water depth measurements.

NOTE 4 — Inaccuracies in soundings are most likely to occur.

a) owing to the departure from the vertical of the sounding rod or line particularly in deep water, when the velocity is high;

b) owing to the penetration of the bed by the sounding line or rod; and

c) owing to the nature of the bed when using an echo-sounder.

Difficulties due to (a) may be avoided by the use, where practicable, of an echo-sounder. The effects of the drag on a sounding line may be reduced by using a streamlined lead weight at the end of a fine wire. A correction should be applied to the wetted length of wire if the wire is not normal to the water surface. It is recommended that the angle should not be greater than 30° in view of the inaccuracies involved. Methods of applying the correction are given in Appendix C.

Difficulties due to (b) may be overcome by fitting a base plate to the lower end of the sounding rod, or by fastening a disc to the end of the sounding line, when they will not cause scour of fine bed material due to high velocities.

NOTE 5 — In certain cases, for example floods, it may be impossible to determine an adequate profile of cross-section during the measurement. For these cases the full profile should be determined by surveying methods, either before or after the measurement; however, it should be recognized that this method is subject to errors due to possible erosions or deposits in the cross-section between the time the profile is determined and the time of measurement.

5.3 Measurement of Velocity

5.3.1 *Measurement of Velocity Using Current Meter*

5.3.1.1 Velocity observations are normally made at the same time and in the same verticals as measurements of the depth. This method is used in the case of unstable beds. Where, however, the two measurements are out of necessity made at different times, the velocity observations shall be taken at a sufficient number of places, ordinarily at least twenty verticals, and the widths of segments shall be measured as described in **5.1.1** and **5.1.2**. The discharge in any one segment should not exceed 10 percent of the total. Selection of verticals according to equi-distance criterion leads to results which are slightly better than those obtained when using the criterion 'segments of equal flow'. A smaller number of verticals may be used if the depth and velocity profiles are uniform.

5.3.1.2 *Number of points in the verticals* — The nature of the velocity profile in the verticals is obtained by measuring velocities at a number of points in each vertical. Although there are many methods as described in **5.3.1.6**, the velocity profile gets sufficiently determined by measurement at four points. The result can be improved by increasing the total measuring time at each point or by increasing the number of points. In practice, for routine observations a two-point method, should generally be preferred instead of a one-point method, although the one-point method is sufficient when there is a previously established relationship between the mean velocity and the measured point velocity.

5.3.1.3 *Calibration and use of current meter* — The procedures shall correspond to those specified in IS : 3910-1966* and IS : 3918-1966†.

5.3.1.4 *Measuring procedure* — The current meter should be held in the desired position in any vertical by means of a wading rod in the case of shallow channels or by suspending it from a cable or rod from a bridge, trolley or boat in the case of deeper channels.

Suspension equipment should conform to IS : 6064-1971‡.

Wherever possible, efforts should be made to avoid measurements by the area-velocity method from a bridge, particularly, high bridges, as such measurements involve large errors. In fact, this should be avoided if the objective is the determination of the stage discharge relationship.

Where, however, measurements must be made from a bridge, the following conditions should be observed in selecting a bridge, where such a choice exists. A suspension bridge or a bridge with fewer piers and spans is to be preferred to a bridge with a greater number of pier obstructions. The piers should be long and slender and streamlined and aligned in the line of flow. The bridge should not be on a curved reach and the approach and exit should be straight. It should confine the whole river flow through the bridge spans. A bridge with less obstructive members facilitating the suspension of the meter without damage and a masonry or RCC structure subject to less wind and traffic vibrations is to be preferred.

In case of a bridge, measurements are more conveniently made on the downstream side from the downstream parapet of a bridge, provided care is taken to avoid drift materials (which is more difficult to observe if measurements are made from the downstream side) from damaging the current meter. In case of railway bridge with open deck, the observations should be taken as far away as possible from the disturbances due to cutwaters. More segments (which may be marked on the bridge members) will be necessary in the vicinity of the piers. Sufficient weights are necessary to minimise the drift of the current meter and reel mounted cranes are preferable to a hand line. While lowering or raising the current meter, special care is required to avoid its damage. The safety of the current meter as well as the turbulence and eddies and separation of the current caused by the easewaters prevent measurements close to the piers and so suitable segmentation, close and yet safely removed from the piers, would enable estimation by extrapolation of the velocity and depth curves to the pier faces. Air line and wet-line corrections as given in Appendix C shall be made for the deflection from the true vertical despite the weight attached for the measurement of depth.

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*Specification for current meters (cup type) for water flow measurement.

†Code of practice for use of current meter (cup type) for water flow measurement.

‡Specification for sounding and suspension equipment.

When a boat is used, the current meter should be held such that it is not affected by the disturbances of flow caused by the boat and measurements should be taken at the front of the boat. The minimum distance from the point of observation to the boat should preferably be greater than 0·6 times the maximum width of the boat.

For measurements made by the one-point method, the current meter should be exposed for 120 seconds or for 150 revolutions whichever occurs later. If measurements are made at more than one point in each vertical, the current meter should be exposed for a period of at least 30 seconds at each point in the vertical. If the water velocity is known to be subject to periodic pulsations, it is advisable that the current meter should be exposed at each selected point for at least two (preferably three consecutive periods) consecutive periods of 60 seconds or for periods of sufficient duration to cover at least two periods of pulsation and the average of all the separate readings is taken as the velocity at the point. The velocity at the point should then be taken to be the average of all the separate readings, unless it is apparent that the difference is due to some cause other than pulsation of the flow.

The current meter should be removed from the water at intervals for examination, usually when passing from one vertical to another.

More than one current meter may be used in determining velocities in the individual verticals, different current meters being used for consecutive verticals. The averaging effect may tend to reduce the systematic error of measurement. Measurements in unsteady flow may be made in accordance with IS : 2914-1964*.

In channels where the flow is unsteady, it is useful to correct for the variations in the total discharge during the period of the measurement not only by observing the change in the stage, but also by continuously measuring the velocity at some conveniently chosen point. Experience has shown that, provided the variations in the discharge are small, the velocity distribution is not modified significantly.

A reference current meter may be positioned in the main current and the velocity at this point measured, if possible, at the same time as each local point velocity measurement in the cross-section is made. All the individual measurements during the test can then be referred to the corresponding reference reading. The mean reference velocity, defined as the average of all the readings of the reference current meter, can be calculated precisely. Each reading of the local point velocity can then be corrected by multiplying by the ratio of the mean reference velocity to the reference velocity reading at the instant being considered. If the reference current meter measurements are not made at the same time as the individual measurements, they should be taken at regular intervals as frequently as possible throughout the measurement and the reference reading appropriate to a local point velocity measurement obtained by interpolation.

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*Recommendations for estimation of discharges by establishing stage discharge relation in open channels.

NOTE 1 — *Effect of Wind* — The wind may affect current meter observation in several ways. If observations are made from a cable car or from suspension bridge, the wind may cause these structures to oscillate, causing the current meter to swing inside water. If a boat is used it may heave due to waves. Besides disturbance so caused, the wind action may cause considerable variation in the surface velocities both in respect of magnitude and direction. If velocities are to be measured at the surface or at 0·2 depth, it is preferable to avoid heavy wind when it is in or against the direction of flow. At all important sites it is desirable to use an anemometer and record the velocity of wind during the observations.

NOTE 2 — *Drift, Aquatic Growth* — When velocities are measured during floods, care should be exercised to ensure that drift materials such as tree branches do not disturb or damage the current meter and its suspension. Aquatic growth on the channel bottom is also likely to interfere with the operation of the current meter observation specially when velocities are measured near the bed or at 0·8 depth.

Wherever possible, effort should be made to avoid a weed-infested reach and locate the measuring station elsewhere. Where it is impossible to find any weed-free site suitable in other respects the following method is likely to yield the best approximation of the flow, but not without a larger error than may normally be expected from measurements at a clear site.

As weeds grow continuously, there is progressively increasing reduction in the effective sectional area and in the velocity and the point of mean velocity along a vertical is also continuously changing. In weed-infested sites, therefore, the point of mean velocity should invariably be determined for each segment of flow during each measurement. Moreover, the number of segments (or verticals) should be relatively larger than in weed-free channels of the same dimensions and discharge. As far as possible, the width of the segment should be fixed on the basis of significant uniformity of weed growth in a segment and the area of the segment scaled down by an appropriate factor based on judgement and experience, for example, the area of the segment may be taken as 0·9 to 0·95 times the total area where the weed growth is light, but only 0·75 to 0·8 times the total area where the weed growth is moderately thick. In other respect, the normal single-point or surface velocity area method may be used until further research.

NOTE 3 — *Effect of Water Temperature* — Temperature has some effect on reading of the current meter. It may, however, be considered negligible for the range of velocities usually measured and for the range of temperature usually met with.

NOTE 4 — *Effect of Proximity of Boundary* — The current meter rating is affected due to proximity of the boundary, bed and banks of the channel and the free surface.

The plane of rotation of the current meter should not be situated at a distance less than one and a half times the rotor height from the water surface, nor should it be at a distance less than three times the rotor height from the bottom of the channel. Besides, no part of the meter should break the surface of the water.

If the velocities are observed at 0·3 m from sides as well as bottom, the current meter observations will be subject to negligible boundary effect (less than ± 0·2 percent). Similarly, experiments have indicated that the cup type meter underregisters when held within 0·15 m of water surface, the error increasing progressively towards the surface. Observations of velocities within 0·3 m below surface of water may be avoided. This is applicable to smooth flumes. In the field a distance of 1 m from the boundary is desirable.

When the current meter is used close to the bed or surface, particularly when there are ripples or waves, additional calibrations should be made under immersed conditions similar to those encountered during the measurement.

NOTE 5 — *Observation at Low Velocity* — A normal cup type current meter suspended from a bobbing boat may be seriously in error if the velocity is of the order of 0·3 m/second or less.

Special current meters, for example, pygmy type giving reliable measurements below this velocity may be used if they have been tested in this range of velocities for repeatability and accuracy, prior to the measurement.

NOTE 6 — *State of Flow* — Current meters are rated in a rating tank where turbulence, eddies, swirls and similar disturbances, are absent. It is, therefore, advisable to avoid observations under excessive turbulence, cross currents, swirls, eddies and similar disturbances.

NOTE 7 — The current meter used within the range of calibration gives the desired accuracy.

5.3.1.5 *Oblique flow* — If oblique flow is unavoidable, the angle of the direction of the flow at a point to the perpendicular to the cross-section must be measured and the measured velocity corrected. Special instruments have been developed for measuring the angle and velocity at a point simultaneously. Where, however, these are not available and there is insignificant wind, the angle of flow throughout the vertical may be taken to be the same as that observed on the surface. If the channel is very deep, or if the local bed profile is changing rapidly, this assumption should not be accepted without checking.

If the measured angle to the perpendicular is γ, then

$$\gamma \text{ corrected} = \gamma \text{ measured } \mathrm{Cos}\ \gamma$$

5.3.1.6 *Methods for mean velocity measurement in each vertical* — The mean velocity of the water in each vertical can be determined by any of the following methods, depending on the time available and having regard to the width and depth of the water, to the bed conditions, and to changing stage and whether there is ice cover, as well as to the accuracy which is to be obtained:

a) Velocity distribution method,

b) Three-point method,

c) Two-point method,

d) One-point method, and

e) Integration method.

a) *Velocity distribution method* — The measurement of velocity by this method shall consist of velocity observations made at a number of points along the vertical between the surface of water and the bed of the channel. The spacing of the measuring points shall be so chosen that the difference of velocities between two adjacent points shall be not more than 20 percent with respect to the higher value of the two. The top and bottom points shall be located respectively as near to the water surface and bed of channel as possible. A graph showing the velocities and the depths at which they were measured shall be drawn. The mean velocity of that vertical and its position shall then be determined from the graph.

When turbulent flow conditions exist, the velocity curve may be extrapolated from the last measurement point to the bed by calculating v_x from:

$$v_x = v_a \left(\frac{x}{a} \right)^{1/m}$$

where

v_x = velocity in the extrapolated zone (at any point at a distance ' x ' from the bed), and

v_a = velocity in the last measurement point (at a distance ' a ' from the bed).

The mean velocity $\bar{v}_x$ between the bottom (or a vertical side) of the channel and the nearest point of measurement (where the measured velocity is v_a) can be calculated directly from the equation:

$$\bar{v}_x = \frac{m}{m+1} v_a$$

Generally m varies between 5 (for coarse sides) and 7 (for smooth sides).

An alternative method of obtaining the velocity in the region beyond the last measuring point is based on the assumption that the velocity for some distance up from the bed of the channel is proportional to the logarithm of the distance x from that boundary. If the observed velocities at points approaching the bed are plotted against $\log x$, then the best-fitting straight line through these points can be extended to the boundary. The velocities close to the boundary can then be read from the graph.

Approximations to the velocity distribution methods are obtained from the six-point method and five-point method as given below:

i) *Six-point method* — Velocity observations are made by exposing the current meter on each vertical at 0·2, 0·4, 0·6 and 0·8 of the depth below the surface and as near as possible to the surface and the bottom. The velocity observations at each position are plotted in graphical form and the mean velocity determined with the aid of a planimeter.

Alternatively, the mean velocity may be found algebraically from the equation

$$\bar{v} = 0{\cdot}1\ (v_{\text{surface}} + 2v_{0{\cdot}2} + 2v_{0{\cdot}4} + 2v_{0{\cdot}6} + 2v_{0{\cdot}8} + v_{\text{bed}})$$

ii) *Five-Point Method* — In this method velocities are measured on each vertical at 0·2, 0·6 and 0·8 of the depth below the surface and as near as possible to the surface and the bottom. The mean velocity may be determined from a graphical plot of the velocity profile with a planimeter, or from the equation

$$\bar{v} = 0{\cdot}1\ (v_{\text{surface}} + 3v_{0{\cdot}2} + 3v_{0{\cdot}6} + 2v_{0{\cdot}8} + v_{\text{bed}})$$

b) *three-point method* — Velocity observations are made by exposing the current meter at each vertical at 0·2, 0·6 and 0·8 of the depth below the surface. The average of the three values may be taken as as the mean velocity in the vertical.

Alternatively, the 0·6 measurement may be weighed and the mean velocity obtained from the equation

$$\bar{v} = 0{\cdot}25\ (v_{0{\cdot}2} + 2v_{0{\cdot}6} + v_{0{\cdot}8})$$

When there is a covering of ice, measurements may be made at 0·15, 0·5 and 0·85 of the depth below the surface, and the mean velocity obtained as the average of these measurements.

c) *Two-point method* — Velocity observations should be made at each vertical by exposing the current meter at 0·2 and 0·8 of the depth below the surface. The average of the two values should be taken as the mean velocity in the vertical.

NOTE — This method is applicable without correction for depths greater than 1 m where measurements are made under ice cover.

d) *One-point method*

i) 0·6 *Depth method* — Velocity observations should be made at each vertical by exposing the current meter at 0·6 of the depth below the surface. The value observed should be taken as the mean velocity in the vertical. The assumption of the point of mean velocity at 0·6 depth should, however, be verified occasionally by the velocity distribution method and a suitable coefficient should be applied if found necessary. When this relation cannot be established, observations may be made at 0·63 depth instead of at 0·6 depth if greater accuracy is desired, since in logarithmic velocity distribution the mean velocity point on the vertical is located at 0·632 depth.

ii) *Alternative one-point method* — Velocity observations should be made at each vertical by exposing the current meter at 0·5 of the depth below the surface. The values observed, multiplied by a coefficient, should be taken as the mean velocity in the vertical. This coefficient should be verified by analysis using the velocity distribution method, but is approximately 0·95.

NOTE — This method is applicable with correction for depths shallower than 1 m where measurements are made under ice cover, the correction factor being taken as 0·88.

iii) *Surface one-point method* — Velocity should be measured at one point just below the surface. The depth of submergence of the current meter should be uniform over all the verticals, and care should be taken to ensure that the current meter observations are not affected by random surface waves and wind. This 'surface' velocity may be converted to the mean velocity in the vertical by multiplying it by a predetermined coefficient.

The coefficient should be computed for all stages by correlating the 'surface' velocity with the velocity at 0·6 depth or, where greater accuracy is desired, with the mean velocity obtained by the integration method.

Where it is not possible to check the coefficient directly, it may be noted for guidance that in general the coefficient varies between 0·84 and 0·90 depending upon the shape of the velocity profile. The higher values between 0·88 and 0·90 are usually obtained when the bed is smooth but values outside this range may occur under special conditions.

NOTE — *Reduction Coefficient Method* — This method shall be used when the velocity of flow of water in rivers in floods is high and it is not possible to lower the current meter to 0·2 and 0·8 of the depth of water. When the river is in low stages, the velocity of the stream at the surface, at 0·2 and at 0·8 depths of water shall be measured by making observations. These observations shall be repeated for different stages of the river and a ratio (reduction coefficient) between the surface velocity, velocity at 0·2 depth, and at 0·8 depth arrived at for different stages of the river. A graph shall be drawn for each observation point showing the reduction coefficient and the stage of the river. These graphs shall be used for finding out the coefficients for other stages of the river where only surface velocity observations are possible. The reduction coefficients so obtained shall be used to determine the average velocities. Where greater accuracy is required, the velocity distribution method shall be used for determining the reduction coefficient for low stages of the river and the coefficient for higher velocities of the river determined as before from graph.

iv) *Continuous one-point method* — In this method, the velocity of water shall be measured continuously at a point the depth of which is between 0·3 to 0·6 of the depth of water, on the selected vertical with a current meter provided with a recording apparatus. This measured velocity shall be averaged for a 24-hour period and a coefficient applied to obtain the mean velocity. The coefficient shall be determined from discharge measurements made at different rates of flow at the section.

e) *Integration method* — In this method, the current meter shall be lowered and raised through the entire depth at each vertical at a uniform rate. The speed at which the meter is lowered or raised should not be more than 5 percent of the mean velocity of flow in the cross-section, and, in any case, it should not be greater than 0·04 m/second. Two complete cycles should be made in each vertical and, if the results differ by more than 10 percent, the measurement shall be repeated.

For calculating the mean velocity in the vertical, the average number of revolutions per second shall be determined and multiplied by the meter calibration coefficient. It should be noted that an error will arise if the current meter is allowed to remain in its lowest position for any appreciable length of time. This method is recommended for general use only in deep water, that is, where the depth is greater than 1 m.

The depth d_1, tested by the integration method and recorded by the recorder as 'lowering depth' is smaller than the depth of the whole vertical by the distance between the rotor axis and the lowest point of the ground-feeler. The unrecorded discharge thus going through the lower part of the vertical may be taken care of by calculating it on the basis of $\bar{v}_a$, the actual mean velocity, had it been integrated up to the bed of the stream. The methods of finding out $\bar{v}_a$ are given below:

a) The actual mean velocity can be measured immediately with the current meter by lifting it so far that the ground-feeler is just free from the ground. The measurement in that position has to last the space of time, the current meter would have needed according to the chosen speed of lowering, to go through two-thirds of the distance between rotor axis, and the lowest point of the ground-feeler.

b) If the actual mean velocity has not been measured according to (a) this may be calculated as follows:

$$\bar{v}_a = \bar{v}_0 + \bar{v}_0 \left(\frac{d - d_1}{2d_1} \right)$$

where

$\bar{v}_a$ = actual mean velocity (had it been integrated up to the bed of the stream),

$\bar{v}_o$ = observed mean velocity,

d = depth of the vertical, and

d_1 = lowering depth (through which the current meter is lowered).

5.3.1.7 *Choice of the method of measurement* — The choice of the method of measurement is governed by dimensions of the channel, namely, the width and depth of the cross-section, distribution of velocities along the vertical, steadiness of flow, time available for the measurement, condition of channel and accuracy needed.

Velocity distribution method **5.3.1.6**(a), two-point method **5.3.1.6**(c), one-point method, 0·6 depth method **5.3.1.6**(d)(i) and integration method **5.3.1.6** (e) can be used when velocities are moderate and it is possible to lower the current meter to the desired depth.

NOTE 1 — Most accurate results are possible with adoption of the velocity distribution method. In bigger sized streams, the time required for completing one set of observations may however be excessive. With greater depths of steeper slopes the velocity may be high and it may not be possible to lower the current meter to the desired depth. The velocity distribution method is therefore more suitable normally at sites where floods are sustained for sufficiently long time and velocities are moderate. When discharge measurements are to be made for calibration of meters or structures, this method is to be preferred. The method also becomes obligatory when vertical velocity distribution is non-logarithmic and very irregular.

NOTE 2 — The three-point method may be used when there is a ice cover.

NOTE 3 — In case of two-point method, time required for observations is less than velocity distribution method and the estimated velocity is within 2 percent of the actual, if velocity distribution is parabolic. The use of two-point (0·2, 0·8 depth) method is permissible in depths equal to and greater than 1·5 metres if the error resulting from the nearness to the bottom is to be limited to less than ± 1 percent. In case of heavy wind in the direction of river flow, the water surface may be agitated which may affect the velocity at 0·2 depth, especially in shallow streams, when this method becomes unsuitable.

NOTE 4 — These limitations about time and disturbance due to wind could mostly be surmounted by adoption of one-point method (0·6 or 0·5 depth method). The time required for observations is still less and since the velocities are measured at 0·6 or 0·5 depth below surface they are not ordinarily affected by wind. The method can be used for depths greater than 0·75 metre of flow. For depths less than 0·75 metre the velocity may be affected due to the proximity of the bottom as explained earlier. This method could yield equally accurate results as obtained by two-point method when its relation to the true average is determined on the basis of field observations on the particular stream.

This method (0·6 depth) is applicable with correction for depths shallower than one metre where measurements are made under ice cover, the correction factor being taken as 0·92.

If the difference between the observed value for the depth at the point of mean velocity and at a 0·6 depth is appreciable, a multiple point method shall be adopted for velocity observations.

In case of rivers in floods, there could be heavy floating drift and velocities may be so big that lowering of current meter to any great depth is impossible and hazardous. Under such circumstances, the choice of surface one-point method may be made.

One-point continuous method should be used where fluctuations in the flow stages are limited while change in discharge may be caused by varying water surface slopes. Such conditions are generally obtained at the tail race channels or below lake outlets.

NOTE 5 — Mean velocity could be observed with sufficient accuracy in depths greater than one metre by using integration method but it requires a special type of current meter. In adopting integration method, a cup type current meter is likely to over-register, whereas a screw type current meter may under-register the true velocity. Sometimes two types of current meters are used and readings are averaged, but the error involved is then indeterminate. A special ' design ' of the current meter can record true cosine component of the velocity which could be used instead of ordinary cup type and propeller type current meters. The integration method is preferable where the velocity distribution over the vertical deviates appreciably from logarithmic shape.

5.3.1.8 *Errors and limitations* — Estimates of the possible errors that may occur when using the various methods detailed in **5.3.1.6** are given in **7**. It should be noted that these estimates are of possible random errors which may occur even when all the precautions noted earlier and below are observed. If the measurement is not made under these conditions, an additional tolerance shall be included when estimating the overall accuracy of the measurement.

Errors may arise:

a) if the flow is unsteady and if material in suspension interferes with the rotation of the current meter;

b) if the direction of flow is not parallel to the axis of the propeller-type current meter, or is oblique to the plane of the cup type current meter, and if the appropriate correction factors are not known accurately;

c) if the current meter is used for measurement of velocity outside the range established by the calibration;

d) if the set-up for measurement (such as rods or cable suspending the current meter, the boat, etc) is different from that used during the calibration of the current meter, in which case a systematic error may be introduced;

e) if there is a significant disturbance of the water surface by wind; and

f) if the current meter is not held steadily in the correct place during the measurement, which is the case when the boat is drifting (*see* Appendix D), or when an oscillating transverse movement occurs. In the latter case the resultant of the flow velocity and the transverse velocity is measured, which at high transverse velocities gives rise to serious positive errors.

5.3.2 *Measurement of Velocity Using Floats* — This method should only be used when it is impossible to employ a current meter because of excessive velocities and depths, or because of the presence of excessive material in suspension, or where velocities are too low for current meter measurement.

5.3.2.1 *Selection of site* — Three cross-sections should be selected along the reach of the channel as described in **4**, at the beginning, midway and at the end of the reach. The cross-sections should be far enough apart for the time which the floats take to pass from one cross-section to the next to be measured accurately. The midway cross-section should be used only for the purpose of checking the velocity measurement between the cross-sections at the beginning and the end of the reach. A minimum duration of float movement of 20 seconds is recommended.

5.3.2.2 *Measuring procedure* — The float should be released far above the upper cross-section to *attain a constant* velocity before reaching the first cross-section. The time at which the float passes each of the three cross-sections is then noted. This procedure should be repeated with the floats at various distances from the bank of the river. The distances of the float from the bank as it passes each cross-section may be determined by suitable optical means, for example, a theodolite.

Increasing the number of floats used to determine the velocity in each segment shall improve the accuracy of the measurement.

The width of the channel should be divided into a certain number of segments equal width. If, however, the channel is very irregular each segment should have approximately the same discharge. The number of segments should not be less than three, but where possible a minimum of five should be used, the actual number of segments depending on the time available for these observations at the particular stage of the river.

5.3.2.3 *Types of float* — The velocity of water in each segment can be determined by:

a) surface floats,

b) double floats, and

c) other types of floats.

NOTE — Separately flowing blocks of ice, provided they are small, can be used as surface floats during ice drifting.

The coefficients for obtaining the mean velocity from the measurements from the various types of floats are given in **5.3.2.4**.

a) *Surface floats** — These may be used during floods when velocity measurements are to be made quickly. They should not be used when their movement is likely to be affected by winds.

b) *Double floats* — These may be used for measurement of velocities in deep rivers. The sub-surface body may be positioned at 0·6 of the depth below the surface, or at other depths to obtain direct velocity measurements at these depths (for example, those given in **5.3.1.6**).

c) *Other types of floats* — Other methods of obtaining the mean velocity in each segment may be used if the bed profile is regular over the measuring reach:

   i) *Sub-surface floats* — These may be used for measurement of velocities in very deep rivers. The length of the sub-surface float, sometimes called the 'multiple floats', which consists of separate elements suitably attached together to permit flexibility and supported by a surface float, should be approximately equal to the water depth, but shall in no case touch the bottom.

   ii) *Velocity rods* — These may be used for measurement of velocities in the case of artificial or other regular channels where the cross-section is uniform, the bed is free from weeds, and the depth of the water is constant. The velocity rod should not touch the bottom and shall conform to IS : 4858-1968†.

   The following relation may be used for determining the mean velocity:

$$V_{\text{mean}} = V_{\text{rod}} \left(1{\cdot}012 - 0{\cdot}116 \sqrt{\frac{d-l}{d}} \right)$$

   where

   d = the depth of water, and

   l = submerged portion of the rod.

   The correction factors calculated by the above formula for various depths (in any event not less than 0·65 depth) are given below:

**See* IS : 3911-1966 'Specification for surface floats' for the requirements.

†Specification for velocity rods.

l (*Submerged Depth*)	*Correction Factor*
0·65 *d*	0·943 4
0·70 *d*	0·948 5
0·75 *d*	0·954 0
0·80 *d*	0·960 0
0·85 *d*	0·967 1
0·90 *d*	0·975 3

5.3.2.4 *Evaluation of velocity* — The float velocity shall be determined by dividing the distance between the cross-sections by the time taken by the float to travel this distance. Several readings of the float velocities shall be taken and the mean of the readings shall be multiplied by the appropriate coefficient to obtain the mean velocity in the segment. The coefficient derived from current meter measurements at the site at a stage as near as possible to that during the float measurement may be used for converting the float velocity to mean velocity.

It is evident that this method necessarily gives an approximation to the float rate.

NOTE 1 — *Surface floats* — Where it is not possible to check the coefficient directly, it may be noted for guidance that in general the coefficient of the surface float varies between 0·84 and 0·90 depending upon the shape of the velocity profile. The higher values are usually obtained when the bed is smooth, but values outside this range may occur under special conditions.

NOTE 2 — *Double floats* — Where it is not possible to check the coefficient directly, it may be noted for guidance that when the sub-surface body is situated at 0·6 of the depth, the coefficient is approximately equal to 1·0, and at 0·5 of the depth, the coefficient is approximately equal to 0·96.

NOTE 3 — *Other types of float* — Where a direct check on the coefficient is not possible, it may be noted that the coefficient of sub-surface floats and velocity rods varies in general over the range 0·8 to 1·0.

5.3.2.5 *Main sources of error* — Errors may occur during the measurement of discharge by floats and the main sources are listed below. They should be taken into consideration when estimating the overall error as given in 7.

Errors may arise:

a) if the coefficient from which the mean velocity is obtained from the float velocity is not known accurately;

b) if a limited number of segments is used for the velocity distribution;

c) if a sub-surface float or velocity rod is used and the depth of the channel is not uniform throughout the measuring reach;

d) if the float does not travel in the centre of the panel due to oblique currents; and

e) if there is wind, but it should be noted that this error is generally less in case of sub-surface floats in comparison with others listed above.

5.4 Measurement at Floods — While discharge measurements at high stages are by nature difficult, they provide valuable data which cannot be obtained otherwise. Special arrangements, such as high speed boats, moving boat technique, etc, have to be employed in such cases. Stage observations, however, should be made continuously either by continuous stage recorders or by observation at frequent intervals during the day, say once in 15 minutes in tidal reaches, and hourly at other sites.

5.5 Frequency of Observation — The frequency of observation depends on the site conditions, the variation of stage and discharge with time and the objects for which measurements are taken. When there is rapid shift in control, or rapid change in stage and discharge, which happens particularly during floods, the observations have to be more frequent, at least once a day. In other cases, the frequency can be reduced depending upon the stability of control.

6. COMPUTATION OF DISCHARGE

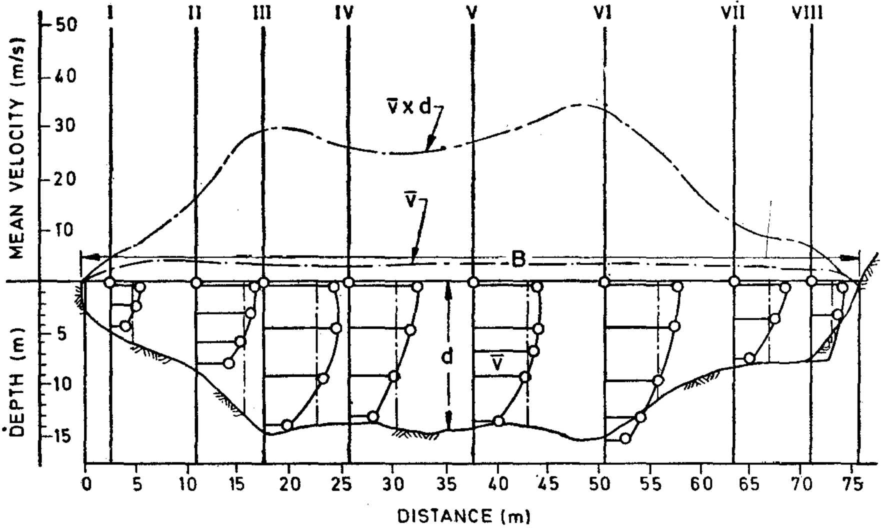
6.1 General — The determination of the mean velocity in each vertical has been dealt with in **5.3.1** and **5.3.2**. In **6.2** and **6.3** the determination of the discharge from current meter measurements and float measurements is given.

6.2 Determination of Discharge from Current Meter Measurement

6.2.1 *Graphical Method (Depth Velocity Integration or Mid-Section Method)* — The value of the product of the mean velocity at each vertical and the corresponding depth, that is $\bar{v}d$, shall be plotted over the water-surface line and a curve drawn through the $\bar{v}d$ points, as shown in Fig. 1.

When velocity measurements are not carried out on the same verticals on which the depth measurements are made, the $\bar{v}$ curve should be plotted across the width of the stream and the value of $\bar{v}$ corresponding to the verticals where depth measurements are made, shall be taken for plotting the $\bar{v}d$ curve.

The area enclosed between this $\bar{v}d$ curve and the water-surface line represents the discharge of the cross-section.



$$Q = \sum_{0}^{B} \bar{v} d \triangle B$$

FIG. 1 COMPUTATION OF DISCHARGE FROM CURRENT-METER MEASUREMENTS DEPTH VELOCITY INTEGRATION METHOD

6.2.2 *Arithmetical Methods*

6.2.2.1 *Mean-section method (vertical plane)* — The cross-section is regarded as being made up of a number of segments, each bounded by two adjacent verticals.

If $\bar{v}_1$ and $\bar{v}_2$ are the mean velocities at the first and second verticals respectively, if d_1 and d_2 are the total depths measured at verticals 1 and 2 respectively, and b is the horizontal interval between the said verticals, the discharge of segment is taken to be:

$$q = \left(\frac{\bar{v}_1 + \bar{v}_2}{2} \right) \left(\frac{d_1 + d_2}{2} \right) b$$

This is repeated for each segment and the total discharge is obtained by adding the discharge from each segment.

NOTE — The additional discharge in the segments between the bank and vertical l, and between vertical m and the other bank, can be estimated from the above equation and on the assumption that the velocity and depth at the banks are zero. If, however, this discharge is a significant proportion of the total flow, then the equation given in **5.3.1.6**(a)c an be used to obtain the mean velocity in the region of the bank.

6.2.2.2 *Mid-section method* — Assuming a straight-line variation of $\bar{v}d$, the discharge in each segment shall be computed by multiplying $\bar{v}d$ by the corresponding width measured along the water-surface line. This width shall be taken to be the sum of half the width from the adjacent vertical to the vertical for which $\bar{v}d$ has been calculated plus half the width from this vertical to the corresponding adjacent vertical on the other side. The value for $\bar{v}d$ in the two half-widths next to the banks shall be taken as zero.

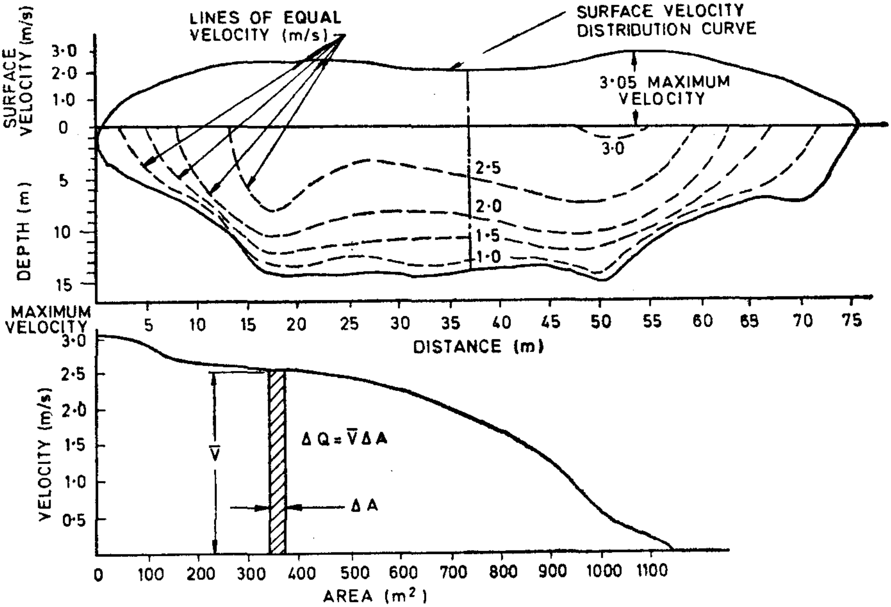
6.2.3 *Area-Velocity Integration Method (Velocity-Contour Method)* — Based on the velocity-distribution curves of the verticals, a velocity distribution diagram for the cross-section (*see* Fig. 2) shall be prepared showing curves of equal velocity. Starting from the maximum, the areas enclosed by the successive equal velocity curves shall be measured by a planimeter and shall be plotted in another diagram (as shown in Fig. 2) with the ordinate indicating the velocity and the abscissa indicating the corresponding area enclosed by the respective velocity curves. The summation of the area enclosed by the velocity-area curves represents the discharge of the cross-section.

6.2.4 *Mean-Section Method : Horizontal Planes* — Instead of determining the mean velocity in each vertical, the mean velocities for a number of horizontal planes can be determined by a corresponding procedure to that given in **5.3.1.6**(a). A similar method to that given in **6.2.2.1** can then be used to determine the discharge.

The use of horizontal and vertical plane computation is particularly suited to measurements in regular shaped channels as it enables a check to be made on the accuracy of the computations.

6.2.5 *Choice of the Method of Computation* — Methods described in **6.2.1** and **6.2.2** are most commonly used and the methods given in **6.2.2** are particularly useful for rapid estimation in the field. Between the mid-section method and the mean-section method, described in **6.2.2**, there is no appreciable difference in the field procedure for either method of computation, but the mid-section method is preferable for the following reasons:

a) the mid-section method yields a little more accurate figure of discharge, it being on an average approximately 0·6 percent closer to the true discharge. Figure 3 gives comparative results of computation of discharge by both the methods.



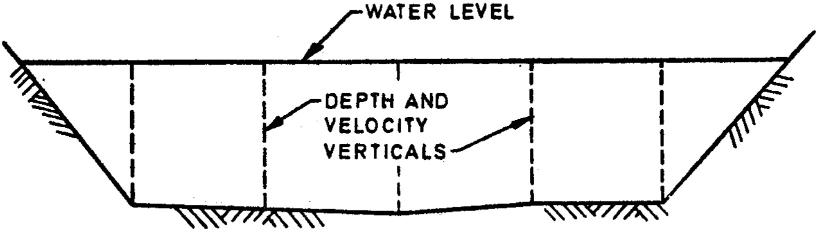
$$Q = \sum_{0}^{A} \bar{v} \, \Delta A$$

FIG. 2 COMPUTATION OF DISCHARGE FROM CURRENT-METER MEASUREMENTS — AREA-VELOCITY INTEGRATION METHOD

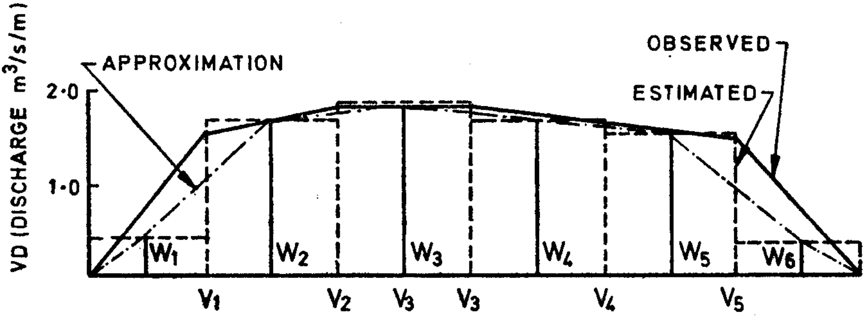
b) the mid-section method results in a considerable saving of time as compared to the mean-section method.

The velocity contour method and the mean-section method on horizontal plane can be used for discharge computations only when the velocity distribution method or six-point method has been adopted for making velocity observations. The method of mean section on horizontal plane is particularly suitable for channels of rectangular cross-section as it enables a check to be made on the accuracy of computations.

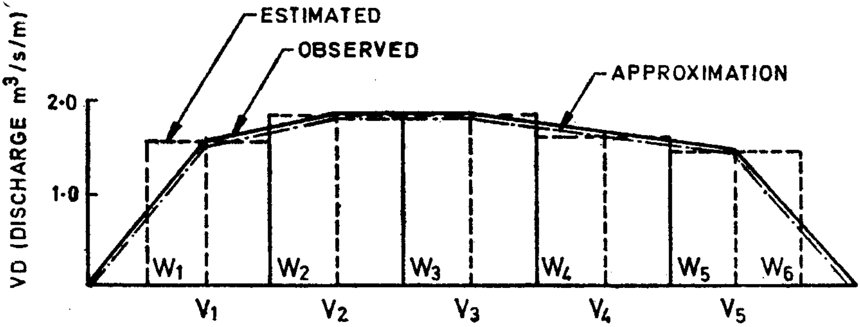
6.3 Determination of Discharge from Surface Float Velocity Measurements — If the upper and lower cross-sections are plotted as shown in Fig. 4, and then divided into a suitable number of segments of equal width the cross-sectional areas of each of these segments can be determined. Halfway between the two cross-sectional lines, another line (*MN* in Fig. 4) shall be drawn parallel to the cross-sectional lines. The starting and ending



CHANNEL CROSS-SECTION
SHOWING DEPTH AND VELOCITY VERTICALS



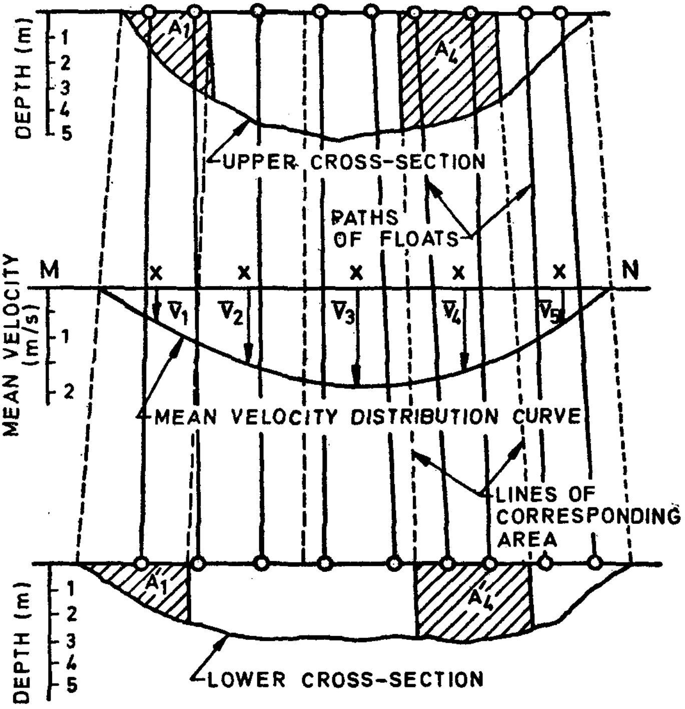
DISCHARGE BY MEAN-SECTION METHOD



DISCHARGE BY MID-SECTION METHOD

FIG. 3 COMPARISON OF MEAN-SECTION AND MID-SECTION METHODS OF COMPUTING DISCHARGE

points of each float can then be plotted and jointed by firm lines, while the surface points separating the various panels of the two cross-sections can be jointed by dotted lines. Where the firm lines cross the line *MN*, the corresponding mean velocity (float velocity multiplied by the appropriate coefficient) shall be plotted normal to *MN* and the end points of these velocity vectors joined to form a velocity distribution curve.



$$Q = \sum_{1}^{m} q = \sum_{1}^{m} \bar{V} \frac{(A + A')}{2}$$

NOTE 1 — *X* indicates the mid-points of the panels in the mid-section.

NOTE 2 — $\bar{V}_1$, $\bar{V}_2$ ... $\bar{V}_5$ are the mean velocities in each of the five panels.

FIG. 4 COMPUTATION OF DISCHARGE FROM FLOAT MEASUREMENT

The mean area of corresponding segments of the upper and lower cross-sections, when multiplied by the mean velocity for this panel as shown by the velocity-distribution curve, represents the discharge through the segment. The summation of the discharges for all the segments is equal to the total discharge. The mean velocity in a panel may be determined by measuring by means of a planimeter the area under the velocity distribution curve for the corresponding segment or, alternatively, an approximate value may be adopted equal to the reading of the velocity halfway across the panel.

NOTE — When it is impossible to obtain satisfactory movement of the floats across the whole width of the river, for instance, if the floats move towards the centre line of the flow, a fictitious discharge may be determined by measuring the mean of the surface velocities. This discharge is to be multiplied by a coefficient, determined from the results of current meter measurements carried out at the level which approximates to that of the float measurements.

6.4 Determination of Discharge for Variations of Water Level — If the fluctuation of water level during the period of velocity measurement is less than 0·05 m, the mean value should be adopted for the computation of the discharge. If the fluctuation is more than this amount, then the discharge should be computed as shown in **6.4.1.** and the mean water level corresponding to this discharge computed as shown in **6.4.2.**

6.4.1 *Computation of Discharge* — The water level shall be plotted in steps for each segment as shown in Fig. 5, or by a smooth curve, and a curve of mean velocity multiplied by actual depth plotted over the stepped or curved water surface line. The area enclosed between this curve and the stepped water surface represents the total discharge.

6.4.2 *Computation of Mean Water Level* — The mean water level representative of the discharge measurement shall be computed from the equations

$$\bar{z} = \frac{\Sigma q_i \bar{z}_i}{Q}$$

and

$$q_i = b_i d_i \bar{v}_i$$

where

$\bar{z}$ = mean water level above the gauge datum,

q_i = partial discharge in the i^{th} segment,

$\bar{z}_i$ = mean level corresponding to the partial discharge q_i.

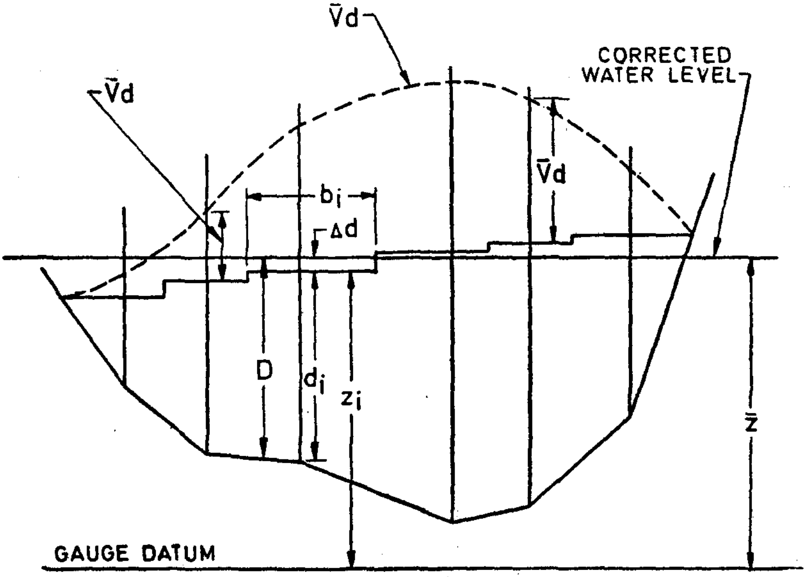
Q = total discharge and equal to the sum of the partial discharge Σq_i,

b_i = width of the i^{th} segment,

d_i = depth of the i^{th} segment, and

$\bar{v}_i$ = mean velocity in the i^{th} segment.

The method is indicated in Fig. 5.



$$\bar{z} = \frac{\sum_{0}^{n} q_i z_i}{Q}$$

$q_i = b_i d_i \bar{v}_i$ $\quad$ n = No. of segments

FIG. 5 COMPUTATION OF DISCHARGE AND MEAN WATER-LEVEL FOR VARIATION OF WATER-LEVEL

6.5 Forms for Recording — Forms for recording shall conform to those specified in IS : 1194-1960*.

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*Forms for recording measurement of flow of water in open channels.

7. UNCERTAINTIES IN FLOW MEASUREMENT

7.0 The uncertainty in a single measurement of discharge is dealt with in ISO 5168 to which reference should be made. In **7.1** a general outline of the method of estimating this uncertainty under conditions of study flow is given. In Appendix E, the individual components of the overall error are examined and examples of these given. It should not be assumed, however, that these are generally applicable and it should be stressed that the observations on which they are based did not include all kinds and sizes of rivers. (*see* ISO/TR 7178).

7.1 Method of Calculation

7.1.1 *Definition of Error* — No measurement of a physical quantity can be free from errors which may be associated with either systematic bias caused by errors in the standardizing equipment or a random scatter caused by a lack of sensitivity of the measuring equipment. The former is unaffected by repeated measurements and can be reduced only if more accurate equipment is used for the measurements. Repetition of the average of m repeated measurements is $\sqrt{m}$ times better than that of any of the points by themselves.

In this clause, the estimated uncertainties of the individual components are derived from percentage standard deviations of the measurements at the 95 percent confidence level and are combined by the root-sum square method to obtain the total uncertainty in a single determination of discharge.

When considering the possible uncertainty of any measurement of the discharge in an open channel, it is not possible to predict this uncertainty exactly, but an analysis of the individual measurements which are required to obtain the discharge can be made and a statistical estimate made of the likely uncertainty. A 95 percent uncertainty on a measurement may be defined statistically as the bandwidth around the calculated value which, on an average of 19 times out of 20 can be expected to include the true value. The uncertainties are therefore given at the 95 percent level.

7.1.2 *Sources of Uncertainties* — The sources of uncertainties may be identified by considering a generalized form of the working equation used for gauging by the velocity-area method:

$$Q = \sum_{i=1}^{m} b_1 \, d_1 \, \bar{v}_1$$

where

Q is the total discharge; and

b_i, d_i and $\bar{v}_i$ are the width, depth and mean velocity of the water in the ith of the m verticals or segments into which the cross-section is divided.

The overall uncertainty in the discharge is then composed of:

a) uncertainties in widths;

b) uncertainties in depths. These shall be determined having regard to **5.2.3**.

c) uncertainties in determination of local point velocities. These will depend on the accuracy of the apparatus and the technique employed and on the irregularity of the velocity distribution in time and space; and

d) *uncertainties in the use of the velocity-area method particularly* those concerned with the number of verticals and the number of points in each vertical. These uncertainties will also depend on the width of the channel, the ratio of width to depth, and the method of computation used.

7.1.3 Determination of individual components of error (as a percentage).

7.1.3.1 *Uncertainties in width* (X_{bi}) — The measurement of the width between verticals is normally based on distance measurements from a reference point on the bank. If the determination is based on the use of a tag-line or measurement of the movement of the wire in the case of a trolley suspension, then the uncertainty in the distance measurement is usually negligible. Where optical of electronic means are used to determine the distances, the uncertainty will depend on the distance measured and the device used.

7.1.3.2 *Uncertainties in depth* (X_{di}) — The uncertainty in depth shall

By analysis of a large number of observations at individual points where the time of measurement is varied, the standard deviation X, can be determined.

In practice, it is found that the percentage uncertainty X_e decreases with an increase in velocity.

b) *Number of points in a vertical* (X_p) — As a general rule, the uncertainty decreases as the number of points per vertical increases. It should be noted that, in the case of the integration method, the measurement is continuous and the two sources of uncertainty, that is, for the number of points and the determination of local point velocities, cannot be separated. The integration method is subject, therefore, to a single source of uncertainty only on this account.

c) *Current meter rating* (X_c) — A small uncertainty will arise in the calibration of the current meter. This will have both a random component and a systematic component, the former arising from the spread of the calibration points about the line of best fit and the latter from any systematic shift of that line or systematic error in the rating tank [*see* **7.1.4**(b)].

d) *Number of verticals* (X_m) — The value of the uncertainty depends not only on the number of verticals but also on the size and shape of the channel, the variations in the bed profile and the horizontal of the velocity profile. It follows that the value in any particular channel will be peculiar to that channel alone. It can only be determined precisely if the discharge can be measured separately by some accurate method or if an extensive investigation of the flow at the cross-section of the channel has already been made.

The percentage uncertainty from this cause decreases with an increase in the number of verticals.

7.1.4 *Overall Uncertainty in the Measurement of Discharge* — The total uncertainty in the measurement of discharge is the resultant of a number of contributory uncertainties which may themselves be composite uncertainties as shown below (for example, the uncertainty in the determination of mean velocity in a vertical), and will, therefore, tend to be normally distributed:

a) *Overall random uncertainty* (X'_Q) – If X'_{b_1}, X'_{d_1}, X'_{e_1}, X'_{p_1} and X'_{c_1} are the percentage random uncertainties in b_1, d_1, e_1, p_1 and c_1 for each of the m verticals, and X'_Q is the percentage random uncertainty in the discharge Q at the 95 percent level, then:

$$X'_Q = \pm \sqrt{X^2_m + \frac{\sum_1^m [(b_i d_i \bar{v}_i)^2 (X'^2_{b_i} + X'^2_{d_i} + X'^2_{e_i} + X'^2_{p_i} + X'^2_{e_i})]}{(\sum_1^m b_i d_i \bar{v}_i)^2}}$$

where

X_m is as defined in **7.1.3.3**.

This equation can be simplified as follows if it is assumed that average values of X'_b X'_d, X'_e, X'_p and X'_c are taken for all verticals, if the number of verticals is more than ten, and particularly if the partial discharges are nearly equal:

$$X'_Q = \pm \left[X^2_m + \frac{1}{m} \cdot (X'^2_b + X'^2_d + X'^2_e + X'^2_p + X'^2_c)\right]^{\frac{1}{2}}$$

NOTE — For special studies, however, the basic equation should be used.

b) *Overall systematic uncertainty* (X''_Q) — The above equations are satisfactory for estimating the precision of the measurement but do not take account of the possibility of systematic uncertainties. Systematic uncertainties which behave as random uncertainties shall be estimated separately and may be combined as follows:

$$X''_Q = \pm \sqrt{X''^2_b + X''^2_d + X''^2_c}$$

where

X_b'', X_d'' and X_c'' are the percentage systematic standard uncertainties in b, d and c.

X''_c is the systematic error of the current meter which varies randomly from instrument to instrument and not the systematic error inherent in the type of instrument or measurement which can be eliminated or determined only if a superior instrument of improved method is available.

c) *Combined uncertainty* (X_Q) — The overall estimate of the uncertainty of the discharge at the 95 percent confidence level will then be:

$$X_Q = \pm \sqrt{X'^2_Q + X''^2_Q}$$

The final presentation of the result should be made by one of the following methods (*see* ISO 5168):

i) Discharge = $Q \pm X_Q$

random uncertainty = $\pm X_Q'$

ii) Discharge $= Q$

random uncertainty $= \pm X_Q'$

systematic uncertainty $= \pm X_Q''$

APPENDIX A

(*Clause* 5.1.1)

METHOD OF CORRECTION FOR SAG, PULL, SLOPE AND TEMPERATURE IN MEASURING THE WIDTH OF THE CROSS-SECTION BY TAPE OR WIRE

A-1. CORRECTION FOR SAG

A-1.1 The correction due to sag of the measuring tape or wire to be applied to the measured length is given by the following formula:

$$k_s = \frac{w^2\, l^3}{24\, F_t^2}$$

where

k_s = sag correction for length (shortening),

w = weight of tape or wire per unit length,

l = actual length of tape or wire which has been previously standardized, and

F_t = total pull applied.

A-1.2 When the tape or wire has been calibrated on the flat, the horizontal distance between the end marks when it is used in catenary shall be obtained by subtracting the sag correction from the calibrated length on the flat. Similarly, if the tape or wire was calibrated in catenary, the true length on the flat should be obtained by adding the catenary correction.

A-1.3 For odd lengths, or lengths differing from that in which the tape or wire was calibrated, the correction for the particular span involved shall be subtracted from that span to give the corrected horizontal distance, if the tape or wire was calibrated on the flat; if it was calibrated in catenary the correction to be applied is given by the equation:

$$k = \left(\frac{x}{l}\, k_s\right) - k_x$$

where

k = correction,

x = length of span involved,

k_s = sag correction for length l, and

k_x = sag correction for length x.

NOTE — The above correction is positive if x is less than l; it is negative if x is greater than l.

A-2. CORRECTION FOR PULL

A-2.1 If the pull applied to the tape or wire is not the same as that used during calibration, the following correction for pull should be applied:

$$k_t = \frac{l(F_t - F_l)}{AE}$$

where

k_t = correction for pull,

l = actual length of tape or wire,

F_t = pull at the time of measurement,

F_l = pull corresponding to l,

A = area of cross-section of tape or wire, and

E = Young's modulus of the material or the tape or wire.

NOTE — As far as possible, a tape or wire should be used under the same pull at which it was calibrated, so that this correction becomes unnecessary.

A-3. CORRECTION FOR SLOPE

A-3.1 The correction for slope, if measured as angle, is given by the equation:

$$k_l = l(1 - \cos\beta)$$

where

k_l = correction for slope, and

β = angle of slope.

A-3.2 The correction for slope, if measured as difference in height, is given by the equation:

$$k_l = \frac{y^2}{2l} - \frac{y^4}{8l^3}$$

where

y = difference in height.

NOTE 1 — The term $\frac{y^4}{8l^3}$ is negligible for a slope of about 8°.

NOTE 2 — This correction is always negative.

A-4. CORRECTION FOR TEMPERATURE

A-4.1 The correction due to temperature variation is negative or positive according to whether the temperature at measurement time is less or more than the temperature at calibration of the tape or wire, and is given by the equation:

$$k_t = l \lambda \theta$$

where

k_t = correction for temperature,

λ = coefficient of thermal expansion, and

θ = increase or decrease in temperature from the temperature at calibration.

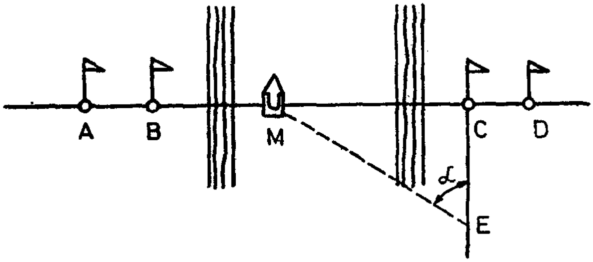
APPENDIX B

(*Clause* 5.1.2)

METHODS OF MEASUREMENT ACROSS THE CROSS-SECTION

B-1. ANGULAR METHOD

B-1.1 A theodolite is set up on one of the banks and angular measurements taken to the boat used for taking soundings and its position fixed (*see* Fig. 6). Alternatively, a sextant may be used from the boat to note the readings to two flags, one fixed on the cross-section and the other at right angles to it.

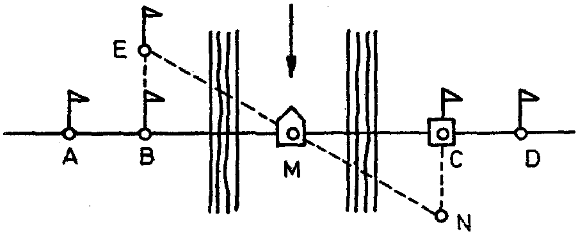


$$MC = CE \tan \alpha$$

FIG. 6 MEASUREMENT OF CROSS-SECTION — ANGULAR METHOD

B-2. LINEAR MEASUREMENT

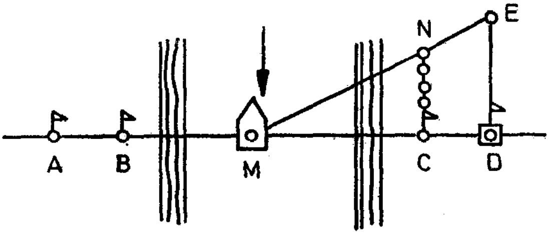
B-2.1 Four flags, *A*, *B*, *C* and *D* are fixed, two on each bank along the cross-section (*see* Fig. 7). One more flag, *E*, is fixed on one of the banks along a line at right angles to the cross-section line and passing through the flag point *B*, nearer to the edge of water and at a known distance from it. An observer, with a flag in his hand, then moves in the opposite bank from *C*, towards a position *N*, along a line perpendicular to the cross-sectional line, until the corresponding Flag *E* on the opposite bank, the flag on the boat *M*, and the flag in his hand *N* are all in one line. The perpendicular distance from the flag in his hand to the cross-section line is determined, and the distance of the boat is computed as follows:



$$MC = \frac{CN \times BC}{BE + CN}$$

FIG. 7 MEASUREMENT OF CROSS-SECTION — PROJECTION FROM OPPOSITE BANK

If the channel is very wide so that objects on the opposite bank are not clearly visible, the position of the boat is fixed from measurements made on one bank only (*see* Fig. 8). Two flags on lines perpendicular to the cross-sectional line, and on the same side, are marked on one bank of the river such that the distance of the boat is computed as follows:



$$MD = \frac{DE \times CD}{DE - CN}$$

FIG. 8 MEASUREMENT OF CROSS-SECTION — PROJECTION FROM ONE BANK

B-3. PIVOT POINT METHOD

B-3.1 When the river is wide and flat land is available, the pivot point method may be used. In Fig. 9, the distance AP is approximately half the width of the river and PD is about one-fifth of AP. On a line DD', points are marked at fixed intervals depending on the width between the selected verticals. The boat moving on the line AA' can be fixed in the selected vertical by lining up with points P and E_1, E_2, etc. A second set of pivot points on the other bank can be used, if required.

B-4. STADIA METHOD

B-4.1 Reading shall be taken on a graduated rod or levelling staff held in the boat from a theodolite having stadia hairs and the distance of boat shall be computed (*see* Fig. 10). This method is, however, subject to errors due to parallax.

B-5. CHOICE OF THE METHOD

B-5.1 The selection of method is governed by the availability of the clear and plain area on the overbank portion, as well as the available equipment.

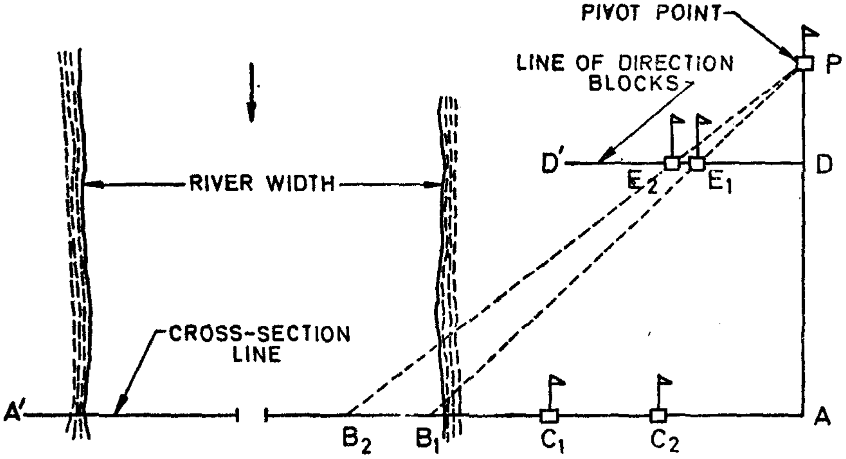


FIG. 9 MEASUREMENT OF CROSS-SECTION — PIVOT POINT METHOD

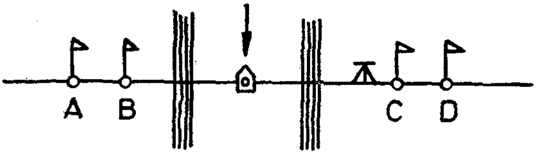


FIG. 10 MEASUREMENT OF CROSS-SECTION — STADIA METHOD

Out of the four methods described above, pivot point method (Fig. 9) is the simplest which does not require any precison angle measuring equipment and it also yields accurate results. This method is, however, feasible when sufficient clear and plain overbank space exists at least on one of the banks. The advantage of this method is that once pivot and other points depending upon the spacing of verticals are fixed and flagged on the ground, the boatman can easily bring the boat to the correct position on the cross-section. The method of linear measurement with projection from one bank (Fig. 8) is merely another version of pivot point method and has similar advantages and disadvantages. The linear method with projection from opposite banks (Fig. 7) has, however, an added advantage that the plain area required on the banks is much narrower.

In case no plain area is available on the banks, the angular or stadia method becomes obligatory. The location of the theodolite on the bank has to be made keeping in view the following requirements:

a) The theodolite location should be well away from the alignment of the cross-section in the angular method.

b) At least one flag on each bank demarcating the alignment of the cross-section should be clearly visible from the location of the theodolite.

c) It should be possible to measure the distance precisely from the theodolite to the flag on the same bank.

Theodolite method can be used in clear or thinly forested area.

Sextant and stadia methods are useful when the river flows in thickly forested or populated area and where ground is uneven.

APPENDIX C

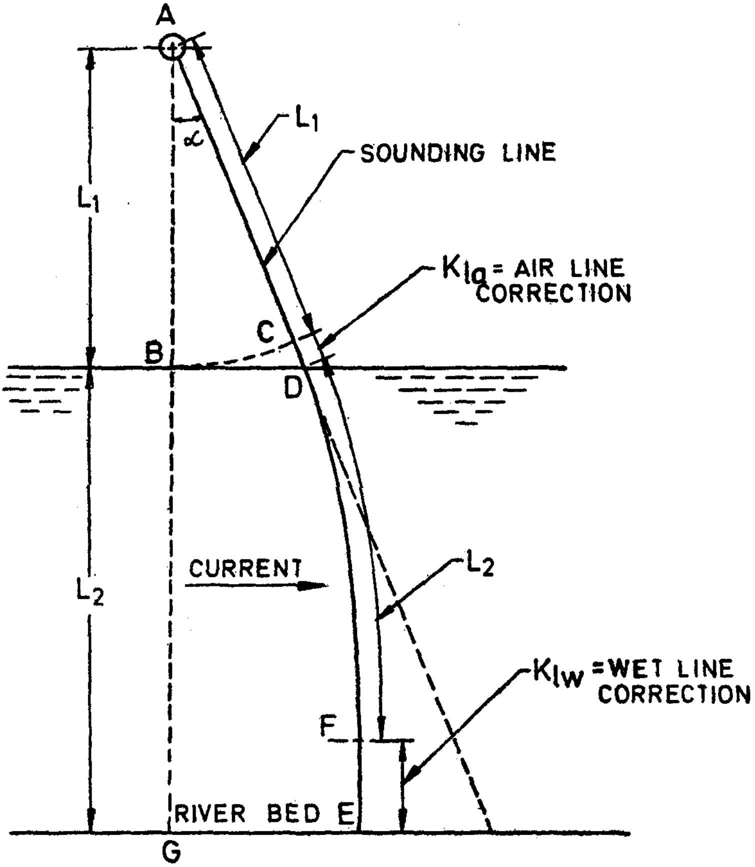
(*Clauses* 5.2.3 *and* 5.3.1.4)

CORRECTIONS FOR WETTED LENGTH OF WIRE WITH MEASURING DEPTHS WITH THE WIRE NOT NORMAL TO THE SURFACE

It should be noted that a correction should be made for the change between the vertical length and slant length of the line above the water surface (*see* Fig. 11). If the point of suspension of the sounding line is at a vertical distance x above the surface and the angle between the sounding line and vertical is α, then the air line correction k_{1a} to be applied is given by the formula:

$$k_{1a} = \left(\frac{1}{\cos \alpha} - 1 \right) x$$

The percentage correction (k_{1a}/x) which should be deducted from the measured length of the sounding line above the water surface, for angles up to 30°, is given in Table 3.



$$K_{la} = (Sec\,\alpha - 1)\, L_1$$

FIG. 11 SOUNDING LINE CORRECTION

TABLE 3 AIR-LINE CORRECTION

Vertical Angle	Correction %	Vertical Angle	Correction %	Vertical Angle	Correction %
4°	0·24	14°	3·06	24°	9·46
6°	0·55	16°	4·03	26°	11·26
8°	0·98	18°	5·15	28°	13·26
10°	1·54	20°	6·42	30°	15·47
12°	2·23	22°	7·85		

The wet-line correction, k_{l_w}, also expressed as a percentage, to be deducted from the measured length of the sounding line below the water surface—called the wet line depth, is estimated on the assumptions that the horizontal drag pressure on the weight in the comparatively still water near the bottom can be neglected, that the velocity distribution in the vertical is normal, and that the sounding wire and the weight are designed to offer little resistance to the water current. The uncertainties in this estimation are such that significant errors may be introduced if the vertical angle is more than 30°.

The corrections given in Table 4 are percentages of wet-line depth.

TABLE 4 WET-LINE CORRECTION

Vertical Angle	Correction %	Vertical Angle	Correction %	Vertical Angle	Correction %
4°	0·06	14°	0·98	24°	2·96
6°	0·16	16°	1·28	26°	3·50
8°	0·32	18°	1·64	28°	4·08
10°	0·50	20°	2·04	30°	4·72
12°	0·72	22°	2·48		

Note — If the horizontal angle of the direction of flow with the perpendicular to the measuring section is more than 15° a correction (additive) is necessary to the observed vertical angle.

APPENDIX D

(*Clause* 5.3.1.8)

CORRECTION FOR DRIFT

Where motor launches are used, they should be of sufficient power to avoid drift under normal conditions. In great depths and high velocities it is sometimes impossible to keep the measuring launch exactly at the desired point. The upstream or downstream and lateral movements of the launch during velocity observation should be measured by appropriate surveying techniques or electronic distance measuring equipment, and a vector analysis made to determine the true velocity corrected for movement of the measuring launch.

For downstream drift in high velocities, the drift can be measured and due allowance made in the velocity measurement. For example, based on 388 observations carried out on the river Indus at Kotri (range of velocities between 1·146 and 2·911 m/second, the correction for drift was obtained statistically with the following formula:

$$\bar{v}_p = 0{\cdot}064 + 0{\cdot}98\,\bar{v}_b + 0{\cdot}98\,\bar{v}_d$$

where

$\bar{v}_p$ = true velocity in metres per second;

$\bar{v}_b$ = velocity in metres per second, observed at the point with the boat drifting; and

$\bar{v}_d$ = drift velocity in metres per second

$$= \frac{\text{drift in metres}}{\text{120 seconds (period of observation)}}$$

In the above set of observations, the velocity without drift was observed by means of a sufficiently powered motor launch, while that with drift was observed by means of a flat-bottomed boat. A two-pronged anchor weighing 28·123 kg was used for partially anchoring the boat, the length of the rope paid out generally varying between 20 and 25 m. After the boat was towed sufficiently upstream, the anchor was dropped, and the velocity was measured while the boat drifted.

The drift velocity was measured from drift flags fixed at known distance apart on both the banks.

APPENDIX E

(*Clause* 7.0)

UNCERTAINTY OF A VELOCITY AREA MEASUREMENT

E-0. It should be noted that the values given in this appendix are the result of investigations carried out since the first publication of ISO 748 in 1968. In particular, reference should be made to the ISO/TR 7178. Nevertheless, it is recommended that each user should determine independently the values of the uncertainties which will apply to a particular case. The values which follow are percentages at the 95 percent confidence level.

E-1. UNCERTAINTIES IN WIDTH (X'_b):

The uncertainty in the measurement of width should be not greater than ±1 percent.

As an example, the error introduced for a particular range finder having a base distance of 800 mm varies approximately as follows:

Range of Width, m	*Absolute Error,* m	*Relative Error,* %
0 to 100	0·3	± 0·3
150	0·5	± 0·4
250	1·2	± 0·5

As another example, the error in the 'pivot point method' of positioning, compared to the angular method with the help of a theodolite, has been determined, with one theodolite and one set of pivot-points on one bank only for rivers up to 600 m wide, but with two theodolites and two sets of pivot-points, one from each bank up to near half of the stream.

The results were as follows:

Range of Width, m	*Absolute Error*, m	*Relative Error* %	*Remarks*
300 to 600	2·3	± 0·4	From one bank
Over 600 to 1 200	6·7	± 0·6	From each of two banks

E-2. UNCERTAINTIES IN DEPTH (X'_d)

For depths up to 0·300 m the uncertainty should not exceed ± 3 percent and for depths over 0·300 m the uncertainty should not exceed ± 1 percent.

As an example, the error in depth in an alluvial river whose depth varied from 2 to 7 m and where the velocity varied up to 1·5 m/second was, for these conditions, of the order of 0·05 m using a suspension cable.

As another example, the errors in depth were taken with the same sounding-rod at the same place up to a depth of 6 m, and beyond that value by a log line with standard air-line and wet-line corrections. These observations were made within the range of 0·087 to 1·3 m/second, the results being as follows:

Range of Depth, m	*Absolute Error*, m	*Relative Error* %	*Remarks*
0·4 to 6	0·04	± 0·7	With sounding-rod
Over 6 to 14	0·05	± 0·4	With log-line and air- and wet-line corrections

E-3. UNCERTAINTIES IN DETERMINATION OF THE MEAN VELOCITY

E-3.1 Times of Exposure (X'_e)

The following values are given as a guide and should be verified by the user. The plus and minus values are given as uncertainties at the 95 percent level.

Velocity m/s	*Point in Vertical*							
	0·2D, 0·4D or 0·6D				0·8D or 0·9D			
	Exposure Time min							
	0·5	1	2	3	0·5	1	2	3
0·050	50	40	30	20	80	60	50	40
0·100	27	22	16	13	33	27	20	17
0·200	15	12	9	7	17	14	10	8
0·300	10	7	6	5	10	7	6	5
0·400	8	6	6	5	8	6	6	5
0·500	8	6	6	4	8	6	6	4
1·000	7	6	6	4	7	6	6	4
Over 1·000	7	6	5	4	7	6	5	4

E-3.2 Number of Points in the Vertical (X'_p)

The following plus or minus values were derived from many samples of irregular vertical velocity curves. They are given as a guide and should be verified by the user:

Method of Measurement	*Uncertainties* (95 *Percent Confidence Level*)
Velocity distribution	1
Five-point	5
Two-point	7
One-point	15

E-3.3 Current Meter Rating (X'_c)

The following plus or minus values are given as a guide and are based on experiments performed in several rating tanks:

Velocity m/s	*Uncertainties* (95 *Percent Confidence Level*)	
	Individual Rating	Group or Standard Rating
0·03	20	20
0·10	5	10
0·15	2·5	5
0·25	2	4
0·50	1	3
Over 0·50	1	2

E-3.4 Number of Verticals (X'_m)

The following plus or minus values are given as a guide and should be verified by the user:

Number of Verticals	*Uncertainties* (95 *Percent Confidence Level*)
5	15
10	9
15	6
20	5
25	4
30	3
35	2
40	2
45	2

E-4. EXAMPLES

Number of verticals : 25

Average velocity in section : 0·25 m/second

Time of exposure : 1 minute

Method : Two-point method

Discharge (group rating) : 50 m³/second

From **E-3.4** $X'_m = \pm 4\%$

E-1 $X'_b = \pm 1\%$

E-2 $X'_d = \pm 1\%$

E-3.1 $X'_e = \pm 10\%$ that is $\frac{1}{2}\left(\frac{12+7}{2} + \frac{14+7}{2}\right)$

E-3.2 $X'_p = \pm 7\%$

E-3.3 $X'_c = \pm 4\%$

The percentage systematic uncertainties may be taken as follows:

$X''_b = \pm 0{\cdot}5\%$

$X''_d = \pm 0{\cdot}5\%$

$X''_c = \pm 0{\cdot}5\%$

Then $X'_Q = \pm \left[4^2 + \frac{1}{25} (1 + 1 + 10^2 + 7^2 + 4^2) \right]^{1/2}$

(*see* **7.1.4**)

$= \pm 4{\cdot}75$

$X''_Q = \pm (0{\cdot}5^2 + 0{\cdot}5^2 + 0{\cdot}5^2)^{1/2}$

$= \pm 0{\cdot}87\%$

Then $X_Q = (4{\cdot}75^2 + 0{\cdot}87^2)^{1/2}$ (*see* **7.1.4**)

$= \pm 4{\cdot}8\%$

say $\pm 5\%$

The result may, therefore, be presented as follows*:

Discharge = 50 m^3/second ± 5%

random uncertainty = ± 4·75% (95% confidence level)

or

Discharge = 50 m^3/second

random uncertainty = ± 4·75% (95% confidence level)

NOTE 1 — A better estimate of X'_e can be obtained by computing the values for each vertical and averaging.

NOTE 2 — The information given in the above tables can also be used to determine the optimum observational procedure for a given accuracy. For example, if the river velocities were all above 0·5 m/second and an accuracy of ± 4 percent was required, 30 verticals would need to be taken, the exposure time would require to be 3 minutes and the two-point method used with an individual rating.

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*see ISO 5168 Measurement of fluid flow — Estimation of uncertainty of a flow-rate measurement.

(*Continued from page* 2)

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INTERNATIONAL SYSTEM OF UNITS (SI UNITS)

Base Units

Quantity	*Unit*	*Symbol*
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Supplementary Unit

Quantity	*Unit*	*Symbol*
Plane angle	radian	rad
Solid angle	steradian	sr

Derived Units

Quantity	*Unit*	*Symbol*	*Definition*
Force	newton	N	1 N = 1 kg.m/s^2
Energy	joule	J	1 J = 1 N.m
Power	watt	W	1 W = 1 J/s
Flux	weber	Wb	1 Wb = 1 V.s
Flux density	tesla	T	1 T = 1 Wb/m^2
Frequency	hertz	Hz	1 Hz = 1 c/s (s^{-1})
Electric conductanc	siemens	S	1 S = 1 1 A/V
Electromotive force	volt	V	1 V = W/A
Pressure, stress	pascal	Pa	1 Pa = 1 N/m^2

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